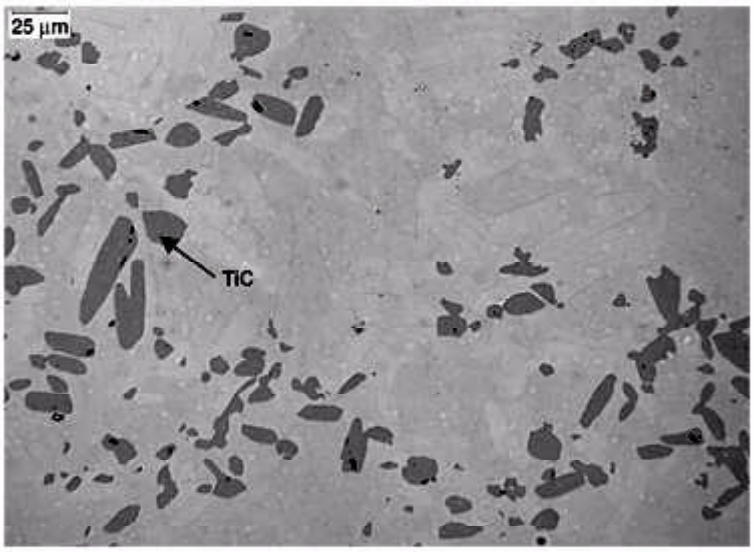
Particulate Titanium Matrix Composites Tested--Show Promise for Space Propulsion Applications

Uniformly distributed particle-strengthened titanium matrix composites (TMCs) can be manufactured at lower cost than many types of continuous-fiber composites. The innovative manufacturing technology combines cold and hot isostatic pressing procedures to produce near-final-shape components. Material stiffness is increased up to 26-percent greater than that of components made with conventional titanium materials at no significant increase in the weight. The improved mechanical performance and low-cost manufacturing capability motivated an independent review to assess the improved properties of ceramic titanium carbide (TiC) particulate-reinforced titanium at elevated temperature.

Researchers at the NASA Glenn Research Center creatively designed and executed deformation and durability tests to reveal operating regimes where these materials could lower the cost and weight of space propulsion systems. The program compares the elevated-temperature performance of titanium alloy Ti-6Al-4V matrix material to an alloy containing 10 wt% of TiC particles (see the following photograph).

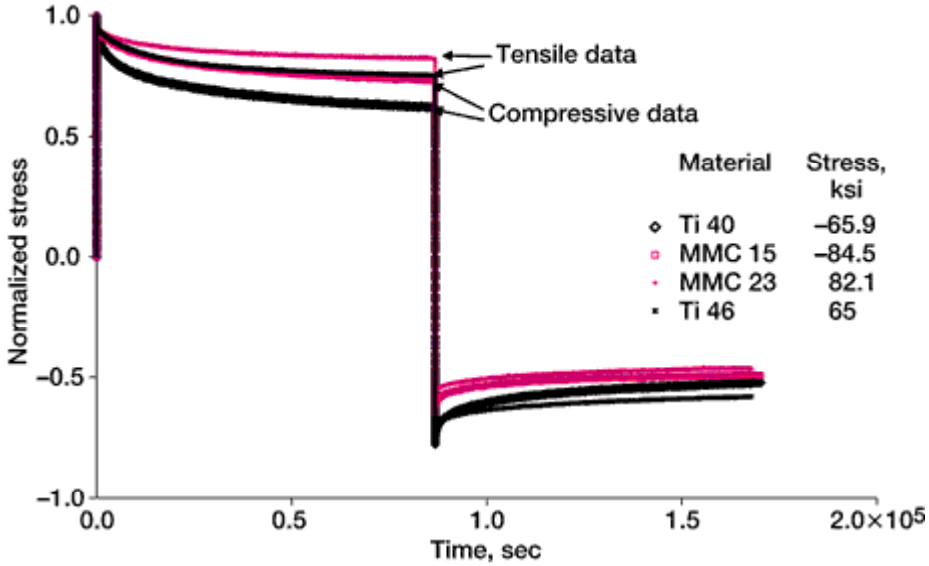


Distribution of titanium carbide particles in a matrix of Ti-6Al-4V.
Long description. Microstructure of the 10-weight percent TiC particles in the Ti-6Al-4V matrix. The particles range from 3 to 50 micrometers.

Initial experiments showed that at these relatively low particle concentrations the material stiffness of the TMC was improved 20 percent over that of the plain Ti-6Al-4V alloy when tested at 427 °C. The proportional limit and ultimate strength of the composite in tension

are 21- and 14-percent greater than those of the plain alloy. Compression tests showed that the proportional limit is about 30 percent greater for TMC than for the plain alloy.

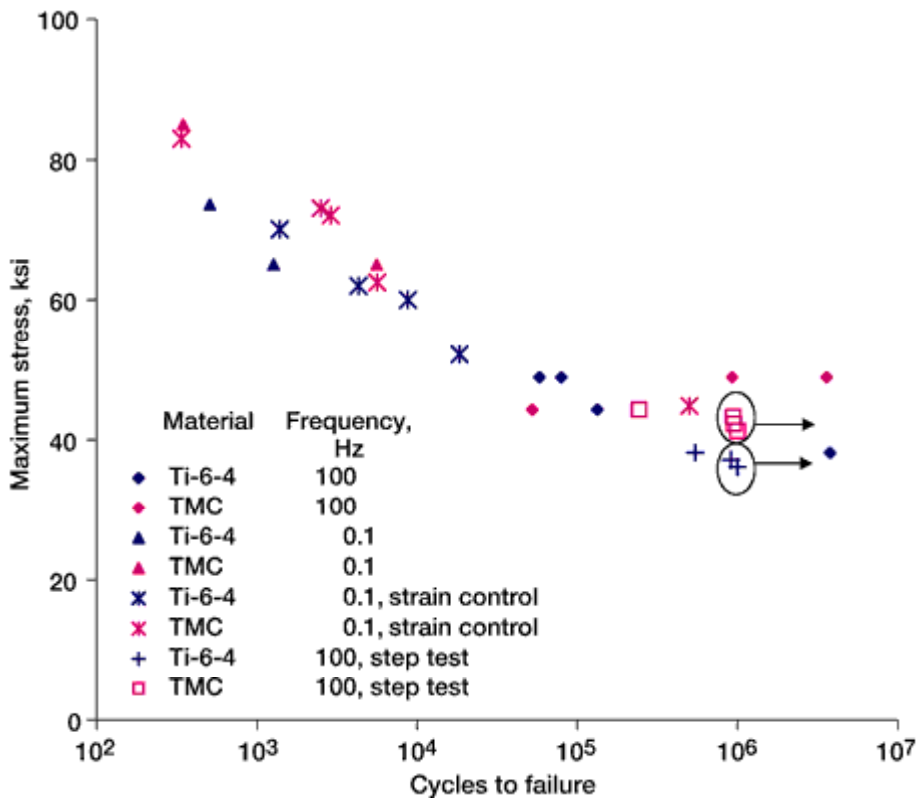
The enhanced deformation resistance of the TMC was also evident in a series of tensile and compressive stress relaxation tests that were made. Specimens were subjected to tensile or compressive strain amplitudes of 0.75 percent for 24 hr followed by a return to zero strain imposed for 24 hr. The stress relaxation data were normalized with respect to the maximum stress for each case and plotted as a function of time in the following graph. Tensile stresses relaxed 19 percent for the TMC and 25 percent for the plain Ti-6Al-4V alloy. Compressive stresses relaxed 25 percent for the TMC and 39 percent for the plain Ti-6Al-4V alloy. The superior deformation resistance of the TMC extends to a creep rate that is 28-percent slower for the TMC when it is loaded to stress levels that are 26-percent higher than for the plain Ti-6Al-4V alloy.



Stress relaxation behavior in tension and compression for both the composite and the neat Ti-6Al-4V alloy. MMC, metal matrix composite.

Long description. Graph of normalized stress versus time in seconds for Ti 40 at -65.9 kips per square inch, MMC 15 at -84.5 kips per square inch, MMC 23 at 82.1 kips per square inch, and Ti 46 at 65 kips per square inch. This figure indicates that the composite offers better resistance to stress relaxation in both tension and compression than does the neat Ti-6Al-4V matrix.

However, the composite's greater deformation resistance and strength is offset by a ductility reduced by one-fifth and a strain-controlled fatigue life reduced by one-third of that of the plain alloy at 427 °C. This prompted a more detailed study of the stress-controlled, low- and high-cycle fatigue response of the TMC. The final graph presents a master plot of new fatigue data, generated in either stress or strain control, plotting maximum stress as a function of cycles to failure. On this basis, TMC fatigue durability appears to be neutral to slightly better than that for the plain Ti-6Al-4V alloy. Furthermore, material stiffness is maintained over the entire life of the TMC specimen.



Slightly improved low-cycle fatigue response of the composite in comparison to the neat Ti-6Al-4V alloy.

Long description. Master plot of new fatigue data, generated in stress control and strain controls, plotting maximum stress (in kips per square inch) as a function of cycles to failure for Ti 6-4 and TMC at 100 and 0.1 Hz (with and without step test and strain control). On this basis, TMC fatigue durability appears neutral to slightly better than that of the plain Ti-6Al-4V alloy.

In conclusion, even a low-concentration particulate-reinforced composite can enhance strength and deformation resistance significantly with no weight penalty and no durability penalty in stress control. These experiments demonstrate that TMC's may reduce the weight and cost of space propulsion components in stress-loaded and stiffness-driven operating regimes. Continuing experiments will examine the fatigue durability of notched samples.

Find out more about this research at http://www.grc.nasa.gov/WWW/LPB/

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